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(1) Explorations of two separate motion-computation systems and the derivation of the functional properties of each. Demonstrated: A dynamic stimulus that causes the first- and second-order motion perception systems to perceive motion in opposite directions, depending on viewing distance. Discovered: Motion/texture interactions--stimuli that are accessible to only to second order motion analysis and then only after their texture has first been extracted. (2) Demonstrated: Perceiving 3D structure from 2D visual inputs depends primarily on the first-order motion perception system. (3) New spatial interaction: A textured area surround by a similar high-contrast texture appears to be of lower contrast when surrounded by neutral gray. This remarkable phenomenon contradicts all current theories of lightness perception. Investigation continuing.

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USAF Office of Scientific Research, Life Sciences Directorate, Visual Information Processing Program

Interim Progress Report, 1 Feb 1988 - 31 Jan 1989

Grant AFOSR 88-0140

Visual Motion Perception

George Sperling, New York University

ABSTRACT

The main activities throughout this grant have been carrying out the experimental research set forth in the proposal (1987), following up promising leads that developed in the course of this work, and preparing manuscripts for publication. The work is best described by the publications and technical reports; these are appended. A brief overview is provided below.

FACILITIES

A highly versatile laboratory has been created for research in almost any area of vision or cognition as described in previous progress reports and the current proposal.

PERSONNEL

Principle investigator, George Sperling, Professor of Psychology and director of the Human Information Processing Laboratory, 20% time (averaged over 12 months). The pronoun we is used in this report to refer to the PI in conjunction with one or more of the other investigators and staff.

Full-time: Research Associate, Dr. Charles Chubb, worked primarily on visual motion and on related mathematical issues.

Systems Programmer, Dr. Penelope Hall, who was visiting NYU from Cambridge, England, on limited-time appointment, completed her tour of duty during the year. It was not possible to find a suitable replacement during the grant year.

Part-time: Dr. Anne Sutter, post-doctoral fellow supported by mainly by NEI (and not at all by USAF) joined the HIP Laboratory in September, 1988. In the part of her work relevant to the current AF project, she set up and began running an experiment comparing perceptual analysis of second-order motion and texture stimuli.

Dr. Barbara Dosher, a consultant who collaborated on projects in motion perception.

Karl Gegenfurtner, a graduate student, who worked partly on attention during this period (supported by ONR) and partly on visual projects related to color processing with John Krauskopf.

Roman Yangarber, a part-time student programmer/research associate worked on this grant for the first half of the grant period. He participated in developing and programming a structure from motion algorithm, a project for which he still owes a report.

Patrick Whelan, a part-time student administrative assistant who did accounting and related tasks, resigned during the grant period and was replaced by Pamela Stark. Ms. Stark has a B.S. in biology and splits her time between serving as administrative assistant on this project, on an ONR project for the same

PI, and her own continuing graduate work.

AFOSR-TR- 89-1021

RESEARCH OVERVIEW

The motion projects described in this report include mainly the specification of nonFourier second-order motion detection systems, algorithms and issues in deriving structure from motion and the psychophysical basis for the kinetic depth effect, spatial interactions in low-level vision, and secondarily, issues in ideal detection and decision theory, and the completion of previously initiated work in object recognition.

Progress is detailed in the papers and manuscripts appended to this report. A brief survey of the work on nonFourier motion perception is provided below.

NonFourier Motion and Texture Perception.

Distance-driven reversal of apparent motion. We studied a collection of stimuli designed to elicit nonFourier motion in one direction and Fourier motion in the opposite direction. Typically these stimuli display nonFourier motion when viewed fovially from short or moderate viewing distances, but reverse direction and display Fourier motion when viewed either peripherally or from far away. These stimuli are extremely useful in placing constraints on the nonlinear transformations mediating nonFourier motion perception. Indeed, one of these stimuli establishes conclusively that at least one nonFourier motion mechanism is mediated by a *full-wave* rectifying transformation as opposed to half-wave rectification.

Texture quilts. We extended the theory of microbalanced random stimuli to allow us to study motion carried exclusively by spatiotemporal modulation of spatial texture characteristics without engaging systems processing the visual signal for other types of motion information. We developed methods for constructing stimuli called *texture quilts* whose motion cannot be seen by either (i) standard motion mechanisms (such as Reichardt detectors) or (ii) mechanisms sensitive to motion carried by any purely temporal transformation of the visual stimulus. Thus, for instance, texture quilts do not systematically stimulate whatever system perceives motion carried by spatiotemporally modulating the flicker rate of spatial visual noise. We have found that it is quite easy to construct texture quilts that display decisive motion. Spatiotemporal modulation of either the orientation or the spatial frequency of spatial texture can carry vivid motion.

The dependency of lightness on texture interactions. We have discovered that the perceived contrast of a patch of texture depends substantially on the contrast of surrounding texture: Indeed, if the surrounding texture is modulated in time between a mean-luminant grey field and a field of high-contrast visual noise, a disc of visual noise of constant contrast situated in the middle of the modulating background appears to undergo a large modulation in antiphase to the background. We demonstrated that no such apparent modulation is induced if (i) the surround and disc are presented in different eyes, or (ii) the texture in the disc is different in spatial frequency content from the surrounding texture.

Publications and Papers in Press

1988 *George Sperling and Thomas R. Riedl, Summation and masking between spatial frequency bands in dynamic natural visual stimuli. *Investigative Ophthalmology and Visual Science, 29, No. 3, ARVO Supplement,* 1988, 139. (Abstract)

1988 *Charles Chubb and George Sperling, Processing Stages in Non-Fourier Motion Perception. *Investigative Ophthalmology and Visual Science, 29, No. 3, ARVO Supplement,* 1988, 266. (Abstract)

1988 Sperling, George. The magical number seven: Information processing then and now. In William Hirst (Ed), *The making of cognitive science: Essays in honor of George A. Miller.* Cambridge, UK: Cambridge University Press, 1988. Pp. 71-80.

1988 Riedl, Thomas R. and George Sperling. Spatial frequency bands in complex visual stimuli: American Sign Language. *Journal of the Optical Society of America A: Optics and Image Science,* 1988, *5*, 606-616.

1988 Chubb, Charles, and George Sperling. Drift-balanced random stimuli: A general basis for studying non-Fourier motion perception. *Journal of the Optical Society of America A: Optics and Image Science,* 1988, *5*, 1986-2006.

1989 Chubb, Charles, and George Sperling. Second-order motion perception: Space-time separable mechanisms. *Proceedings: Workshop on Visual Motion.* (March 20-22, 1989, Irvine, California.) Washington, D.C: IEEE COmputer Society Press, 1989. Pp. 126-138.

1989 Chubb, Charles, and George Sperling. Two motion perception mechanisms revealed by distance driven reversal of apparent motion. *Proceedings of the National Academy of Sciences, USA,* 1989, *86*, 2985-2989.

1989 Dosher, Barbara A., Michael S. Landy, and George Sperling. Ratings of kinetic depth in multi-dot displays. *Journal of Experimental Psychology: Human Perception and Performance,* 1989, *15*. (In press, November, 1989).

1989 Sperling, George, Michael S. Landy, Barbara A. Dosher, and Mark E. Perkins. The kinetic depth effect and the identification of shape. *Journal of Experimental Psychology: Human Perception and Performance,* 1989, *15*. (In press, November, 1989).

1989 Sperling, George. Three stages and two systems of [illegible] processing. Mathematical Studies in Perception and Cognition, 89-1 (Rev), New York University, Department of Psychology, 1989. Pp. 30, Figs. 3. (Accepted for publication in Prazdny M[illegible]ial Issue, Spatial Vision, 1989.)

1989 Barbara A. Dosher, Landy, Michael S., and George Sperling. Kinetic depth effect and optic flow: 1. 3D shape from Fourier motion. *(Accepted for publication in Vision Research.)*

Papers Under Submission for Publication, Technical Reports

1988 Parish, David H. and George Sperling, Object spatial frequencies, retinal spatial frequencies, and the efficiency of letter discrimination. (Under revision, Vision Research.)

1988 Parish, David H., Sperling, George, and Landy, Michael, S. Intelligent temporal subsampling of American Sign Language using event boundaries. *Mathematical Studies in Perception and Cognition, 87-8,* New York University, Department of Psychology, 1987. Pp. 30, Figs. 8. (Accepted for publication, Journal of Experimental Psychology: Human Perception and Performance.)

1987 Farrell, Joyce E., M. Pavel, and George Sperling. The visible persistence of stimuli in stroboscopic motion. *Mathematical Studies in Perception and Cognition, 87-9,* New York University, Department of Psychology, 1987. Pp. 20, Figs. 9. (Submitted for publication.)

1988 Sperling, George, and Erich Weichselgartner. Movement dynamics of spatial attention. *Mathematical Studies in Perception and Cognition, 88-14),* New York University, Department of Psychology, 1988. Pp. 36, Figs. 9.

1988 Landy, Michael S., Barbara A. Dosher, George Sperling, and Mark E. Perkins. Kinetic depth effect and optic flow: 2. Fourier and non-Fourier motion. *Mathematical Studies in Perception and Cognition, 88-4,* New York University, Department of Psychology, 1988. Pp. 45, Figs. 6.

George Sperling and Thomas R. Riedl. Summation and masking between spatial frequency bands in dynamic natural visual stimuli Investigative Opthalmology and Visual Science, 1988, **29, No. 3,** *ARVO Supplement, 139*

SUMMATION AND MASKING BETWEEN SPATIAL FREQUENCY BANDS IN DYNAMIC NATURAL VISUAL STIMULI

George Sperling and Thomas R. Riedl, New York University

Dynamic images of a signer producing individual signs of American Sign Language (ASL) were bandpass filtered in adjacent spatial frequency bands. Intelligibility of a band was determined by testing deaf subjects fluent in ASL. By iteratively varying the center frequencies and bandwidths of the spatial bandpass filters, it was possible to divide the original signal (96 × 64 pixels) into four adjacent, intelligible, frequency bands with mean frequencies of 3.0, 7.5, 15, and 25 cycles per frame-width. All bands were found to have the same temporal frequency spectrum up to a multiplicative constant.

Masking of signals in band i by noise in band j (4×4 conditions) was measured by a rating method. The power ratio within a band i, $P_{signal}(i)/P_{noise}(i)$, required to produce a criterion rating response was the same for bands 2, 3, 4 and higher for band 1 (3 c/frame). The logorithm of the normalized crossband masking effectiveness was inversely proportional to $\log |(.7 freq_{signal}/freq_{noise})|$. The 0.7 indicates an asymmetry: Masking of high frequency signals by low frequency noise is slighly greater the masking of low frequencies by highs.

Weak signals from bands i and j were linearly added and tested for intelligibility. Intelligibility was slighly greater for signals in the same band ($i=j$) versus adjacent bands, and for adjacent bands versus distant bands. Obviously, for *strong* signals, adding different bands produces more-intelligible combinations than does increasing power within a band.

The high intelligibility achieved by the narrow bands of our low resolution signals indicates that high-resolution broad-spectrum signals could be decomposed into many nonoverlapping frequency bands, each of which contained sufficient information for interpreting ASL.[1]

[1]Supported in part by AFOSR Life Sciences Directorate Grant 85-0364 and NSF Science and Technology to Aid the Handicapped, Grant PFR-80171189.

Charles Chubb and George Sperling. Processing Stages in Non-Fourier Motion Perception. *Investigative Ophthalmology and Visual Science, 1988,* **29, No. 3,** *ARVO Supplement,* 266.

PROCESSING STAGES IN NON-FOURIER MOTION PERCEPTION

Charles Chubb and George Sperling, New York University

Most recent motion-perception models propose detectors that are more or less sharply tuned to stimulus energy at various spatio-temporal frequencies.[1] However, it is easy to construct random stimuli which *do not* systemmatically excite such Fourier-energy analytic mechanisms and which nonetheless display strong, consistent apparent motion across independent realizations (Chubb & Sperling, ARVO, 1987). We show that two initial stages, a linear bandpass filter followed by a rectifier (absolute value, square) would suffice to expose the motion information carried by most nonFourier stimuli to subsequent Fourier-energy analysis. However, we further demonstrate apparently moving stimuli that would require two successive pairs of linear filtering and rectification stages in order to be sensed by a Fourier-energy analyzer.

Both the optimal spatial frequency and the sensitivity of the nonFourier mechanism are lower than those of the Fourier-energy mechanism. We use these differences to construct apparently moving stimuli that grossly violate scale invariance: from afar, they are seen moving in one direction by the Fourier mechanism; from close, they are seen moving in the opposite direction by the nonFourier mechanism.[2]

[1]van Santen, J. P. H. & Sperling, G. *J. Opt. Soc. Am. A* 1985, 2, 300-321.

[2]Supported by AFOSR Life Sciences Directorate Grant 85-0364.